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REPORT NO. 1

PROCESS MODELING OF BIOLOGICAL WASTE TREATMENT

ANNUAL PROGRESS REPORT

D. M. Himmelblau
E. F. Gloyna

OCTOBER 15, 1969

Supported by

U.S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Washington, D.C. 20315

Contract No. DADA 17-69-C-9073

The University of Texas
Austin, Texas 78712

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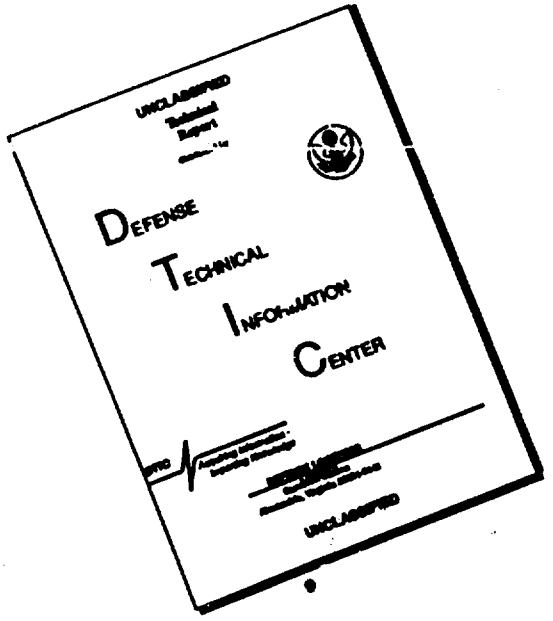

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SUMMARY

This report describes the work undertaken to represent and identify mathematical models of biological waste treatment as applied to a laboratory sized aeration basin. Pulse inputs of radioactive sodium-24 have been used to obtain residence time distribution curves (impulse response curves) for the basin. At all reasonable air flow rates which would support a biomass, the tank appears to be well mixed as might be expected. Reproducible experimental data are easy to obtain, and the basin parameters computed from the data agree well with the known parameters.

FOREWORD

This investigation was authorized under contract DADA-17-69-C-9073 dated February 1, 1969, and is associated with the work of the Center for Research in Water Resources of The University of Texas.

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OBJECTIVES AND SCOPE OF INVESTIGATION

Improvement in the prediction of waste purification rates requires better mathematical models of such processes as well as better data. The purpose of this investigation has been to study the modeling and identification of aerobic waste treatment methods, and to apply population balance techniques of process modeling to laboratory scale equipment in order to ascertain their representativeness.

EXPERIMENTAL WORK

A laboratory sized aeration basin has been used in the first phase of the experimental work to collect data for analysis. Figure 1 illustrates the schematic layout of the experimental apparatus. The entire apparatus is mounted on a rigid structural frame. From a thirty-gallon polyethylene feed tank, the liquid feed passes through rotameters and into the laboratory scale aeration basin. An overhead section of about two feet in length has been added to the laboratory aeration chamber in order to prevent radioactive mist from being carried out of the system. Inasmuch as the solution is radioactive, it is important not to contaminate the surroundings, and as an extra safety factor a separate scrubber has been placed in series with the aeration chamber in order to remove any final carry over. The air supply rate is metered through rotameters.

Originally it was anticipated that the overflow from the aeration basin could be monitored continuously by placing a shielded (with lead bricks) scintillation counter directly over the exit stream. However, the background radiation was found to be far too high with such an experimental set-up; the signal to noise ratio for the "tail" of the process response curve was far too low. Rather than add extensive and expensive shielding around the aeration basin that perhaps would not entirely resolve the problem, it was decided to abandon the continuous monitoring and instead collect batch samples that could be counted at some distance from the aeration basin. A rotating fraction collector was purchased and the overflow line modified with solenoid values so that samples of the overflow could be collected at preselected intervals. Each sample is now counted independently by the shielded scintillation counter permitting replicate counts but adding greatly to the effort required to complete one process run.

To date the vessel has been operated without a biomass being present in order to examine the characteristics of the mixing in the aeration chamber without reaction. Sodium-24, prepared in the University of Texas Nuclear Reactor Laboratory, has been the radioactive tracer used to ascertain the best signal to noise ratio for the scintillation counter as well as carry out the test experiments. A pulse of about 4 mc of sodium-24 is injected into the aeration basin and about 100 to 200 samples of the output stream are collected for a period of up to 4 to 5 residence times. The counting rates at various times measured from the injection of the sodium-24 provide the raw data for analysis by a computer program (described below).

Data from two typical runs are illustrated by the circles in Figures 2 and 3. Because two primary controllable variables are involved in the experiments, the air rate and the water rate, a 2-factorial experiment has been run to ascertain the nature of the mixing in the aeration basin. As expected, the aeration basin acts as a well mixed tank at any reasonable air flow rate that could support a biomass. The known residence time ($t = V/F$) from measurements of the volume of the basin and the flow rate agree quite well with residence times computed from the counting data. For data in Figures 2 and 3, for example, the residence times were respectively

$$\left(\frac{V}{F}\right)_1 = \frac{7400 \text{ ml}}{(60.5 \text{ ml/min})(60 \text{ min/hr})} = 2.04 \text{ hr.}$$

$$\left(\frac{V}{F}\right)_2 = \frac{7100 \text{ ml}}{(203 \text{ ml/min})(60 \text{ min/hr})} = 0.578 \text{ hr.}$$

The two hours corresponds to realistic residence times for municipal waste disposal plants.

ANALYSIS OF DATA

If a pulse of a tracer is injected in the inlet of a continuous process apparatus and the outlet concentration of the tracer is measured, the output curve of tracer concentration vs. time, or

the residence time distribution can be used to characterize the process in so far as mixing is concerned. The tracer must satisfy several conditions:

(a) it must have a negligible volume to avoid changes in the process flow at the moment of injection,

(b) it must be detectable in low concentrations,

(c) it must not influence the physical properties of the fluid, and

(d) it must not be adsorbed or undergo a chemical reaction.

The measured residence time distribution can be compared to the theoretical distributions associated with the idealized extremes of

(a) plug flow with axial mixing, and

(b) a cascade of perfect mixers.

Here we are interested in the latter type of modeling.

The residence time distribution function E(t) for a process with a reaction is defined as follows

$$\frac{c}{c_0} = \int_0^\infty e^{-Kt}\, E(t)\, dt \cong \sum_0^\infty e^{-Kt_i}\, E(t_i)\Delta t_i \qquad (1)$$

where (c/c_0) is the fraction of tracer in the output stream for an impulse input and K is the reaction rate constant (here 0). A computer program developed to evaluate the essential variables and parameters from the raw experimental data includes the following phases

(1) correction of the tracer counting rate for the decay from time of injection of the tracer pulse;

(2) numerical integration of the function $\int_0^\infty c\, dt$ that serves as a normalizing factor;

(3) computation of the residence time distribution function E(t) and the dimensionless residence time distribution function $E(\theta)$;

(4) evaluation of the process parameters.

The [illegible] follows

1) Correction of the observed counting rate for background and radioactive decay

$$n^* = n e^{\lambda t} - n_b e^{\lambda t}$$

where n^* = corrected counting rate
n = observed counting rate
n_b = observed background counting rate
λ = half-life of tracer
t = time

2) Integration of the corrected counting rate

$$\tau = \sum \bar{n}_i^* \Delta t_i$$

where t^* = time of collection of sample
i = index for time

$$\bar{n}_i^* = \frac{n_{i+1}^* + n_i^*}{2}$$

$$\Delta t_i = t_{i+1} - t_i^*$$

3) Determination of residence time distribution function

$$E(t) = \bar{n}^*/\tau$$

4) Calculation of mean residence time

$$\bar{t} = \sum \frac{E_{i+1}^* + E_i^*}{2} \Delta t_i$$

where $E^* = t^* E(t)$

5) Calculation of the dimensionless residence time distribution function

$$E(\theta) = E(t)\bar{t}$$

where $\theta = t^*/\tau$

(5) Calculation of the equivalent number of well mixed tanks, N

$$\theta_y = \theta_i F_i(\theta)$$

$$\tilde{x}_i = \frac{\theta_{y,i+1} + \theta_{y,i}}{2}$$

$$\Delta\theta_i = \theta_{i+1} - \theta_i$$

$$\bar{E} = \Sigma \tilde{x}_i \Delta\theta_i$$

$$V(\theta) = (\theta_{i+1} - \bar{E})^2$$

$$F^*(\theta) = \Sigma V(\theta)\, E(\theta)$$

$$\bar{F}_i(\theta) = \frac{F^*_{i+1}(\theta) + F_i^*(\theta)}{2}$$

$$\sigma^2 = \Sigma \bar{F}_i(\theta) \Delta\theta_i$$

$$N = 1/\sigma^2$$

CONCLUSIONS

Inspection of Figures 2 and 3 illustrates that the laboratory apparatus acts as a well mixed tank under all reasonable air and water flow rates. Premature termination of the observations at about four residence times caused the number of equivalent tanks to be greater than unity for the data of Figure 3. Superposition of the two figures indicates that the response of the process is almost exactly the same despite the different operating conditions.

PLANS FOR FUTURE WORK

Now that the mixing characteristics of the laboratory aeration basin have been determined without a biomass, the next step is to operate the process with a biomass present. A more extended series

of runs will be required so that the mixing and reaction parameters of the process can be evaluated. If these are successful, it would then be possible to make a new aeration basin that did not operate as a single well mixed tank and continue the experimentation under conditions more appropriate to real process equipment.

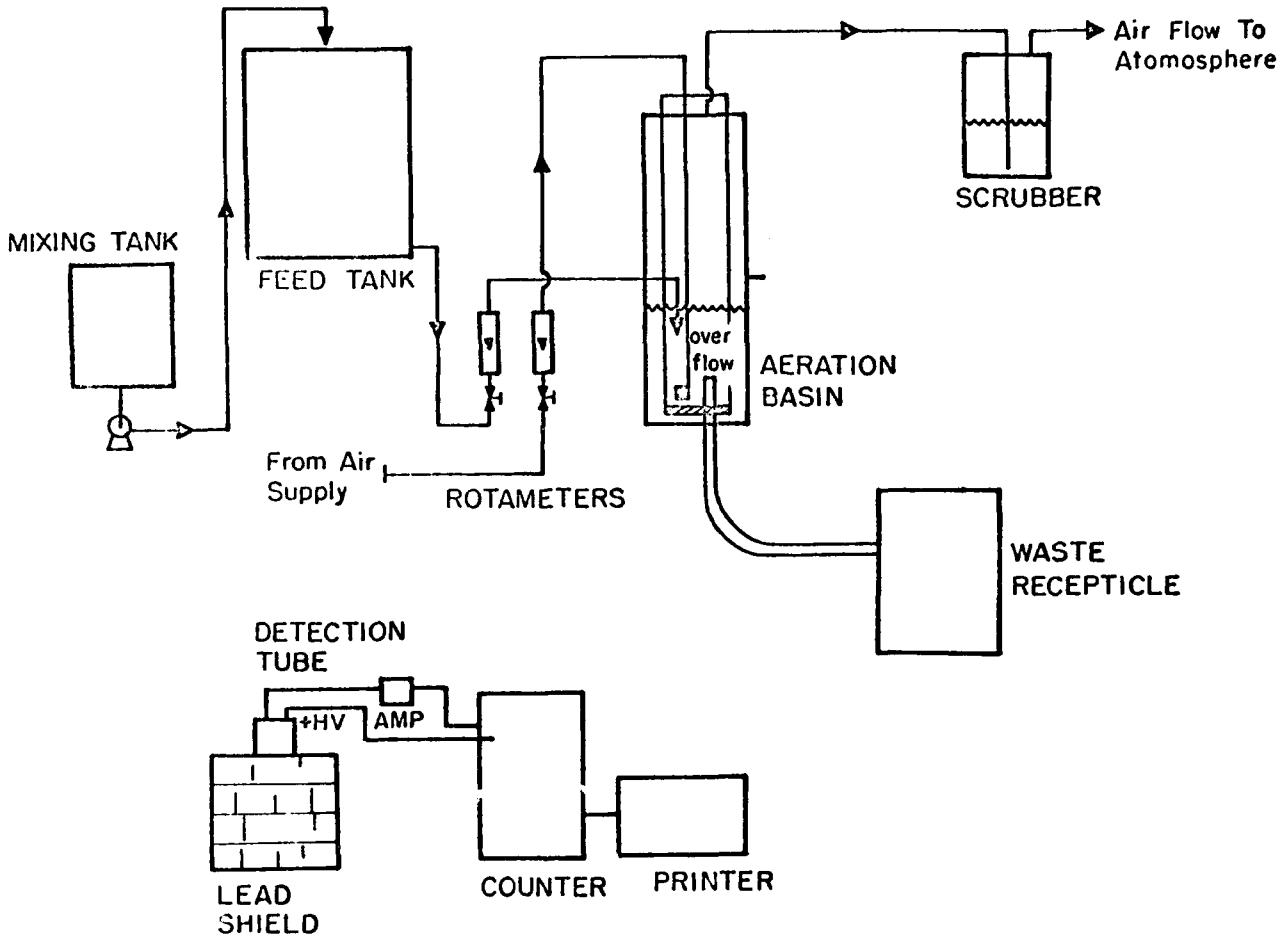
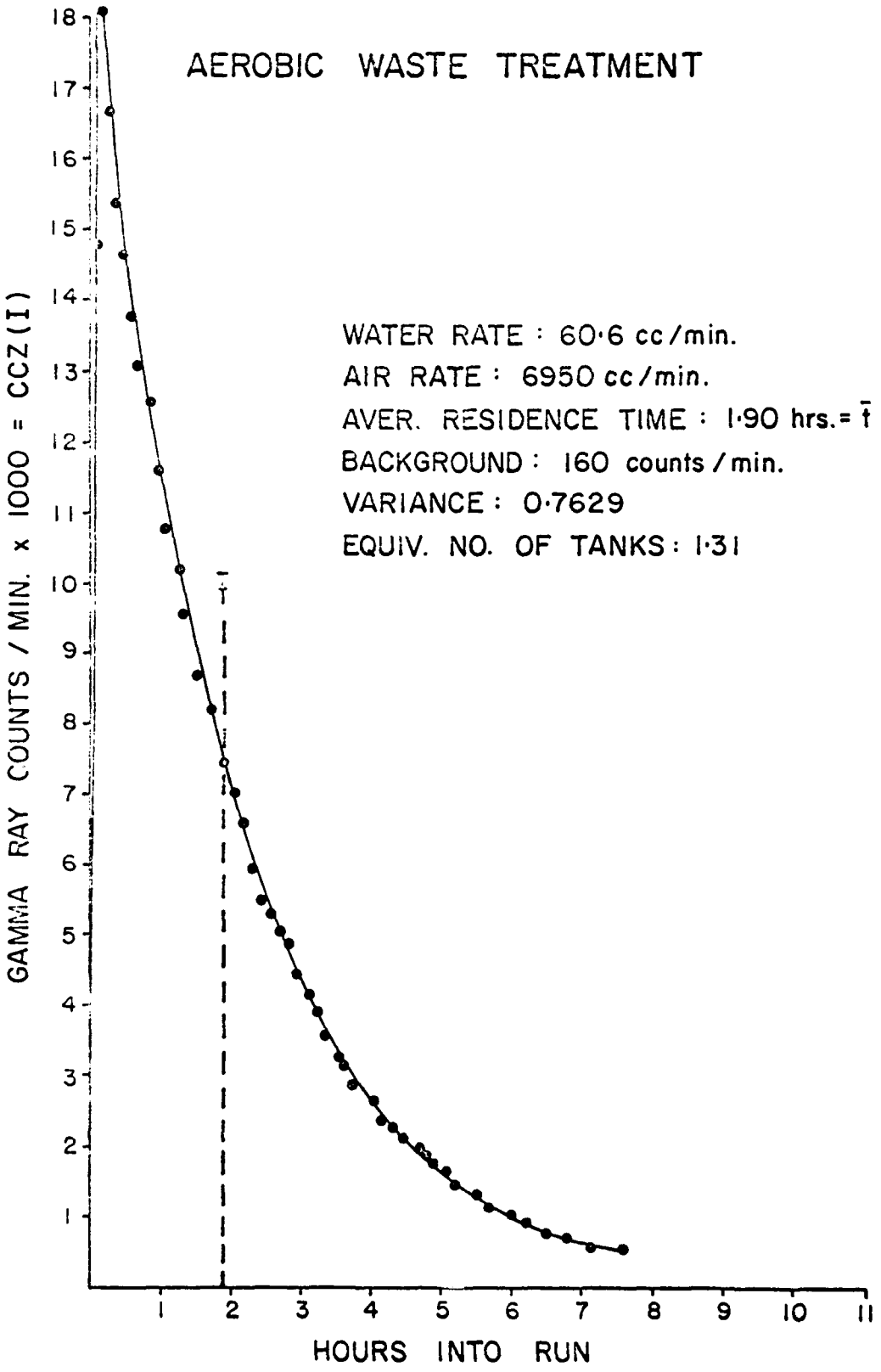
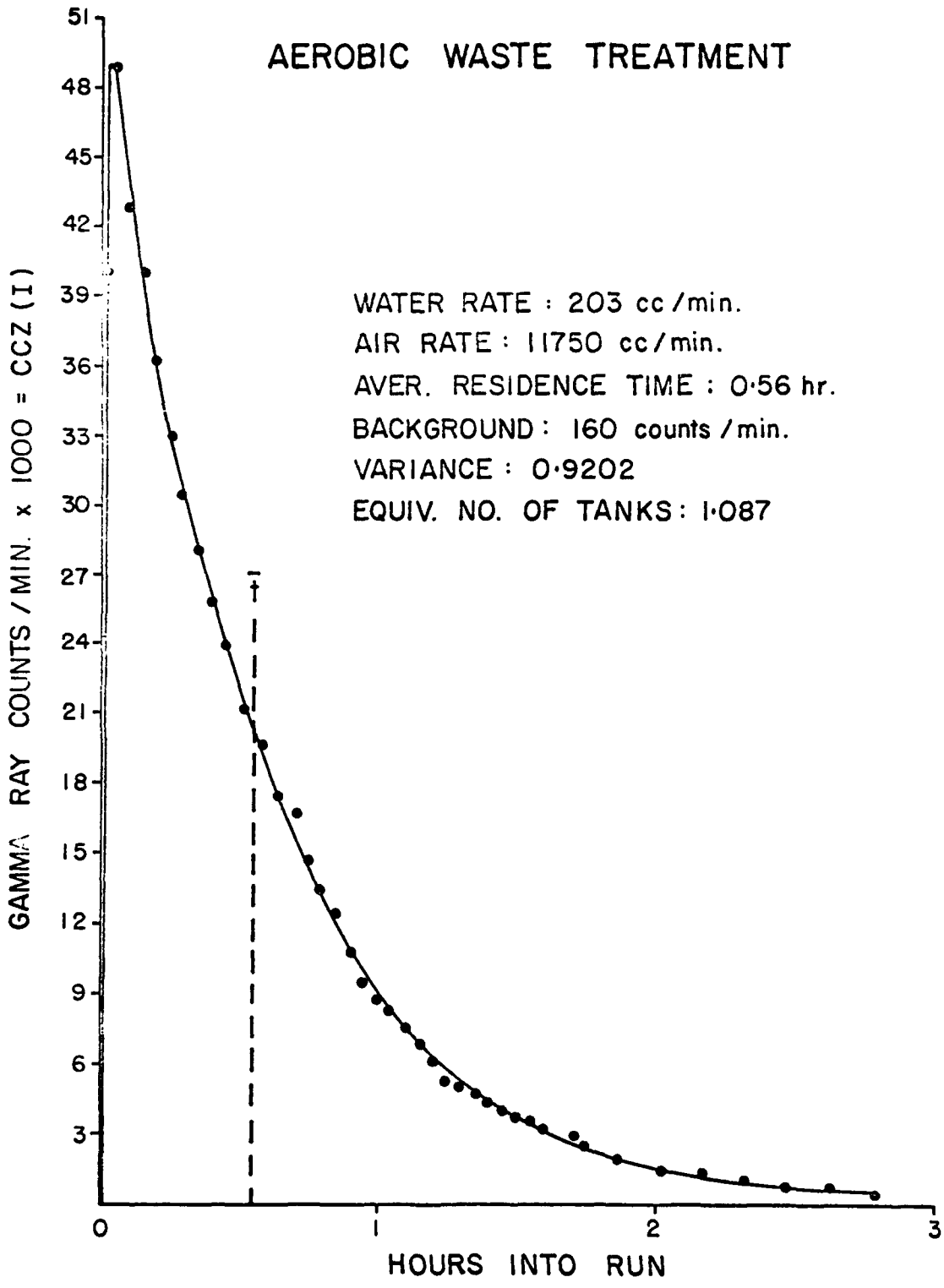


FIGURE 1. SCHEMATIC FLOW DIAGRAM FOR LABORATORY AERATION BASIN.


AEROBIC WASTE TREATMENT
WATER RATE : 60·6 cc/min.
AIR RATE : 6950 cc/min.
AVER. RESIDENCE TIME : 1·90 hrs. = t̄
BACKGROUND : 160 counts/min.
VARIANCE : 0·7629
EQUIV. NO. OF TANKS : 1·31
GAMMA RAY COUNTS / MIN. x 1000 = CCZ(I)
HOURS INTO RUN
t̄


AEROBIC WASTE TREATMENT
WATER RATE : 203 cc/min.
AIR RATE : 11750 cc/min.
AVER. RESIDENCE TIME : 0·56 hr.
BACKGROUND : 160 counts/min.
VARIANCE : 0·9202
EQUIV. NO. OF TANKS : 1·087
GAMMA RAY COUNTS / MIN. x 1000 = CCZ (I)
51
48
45
42
39
36
33
30
27
24
21
18
15
12
9
6
3
0
1
2
3
HOURS INTO RUN

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13. ABSTRACT

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Mixing						
Modeling						
Radioactive counting						
Residence time distribution functions						
Tracer studies						
Waste disposal						

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